

THERMOPHYSICAL MODEL DEVELOPMENT TO SIMULATE NON-GRAVITATIONAL ACCELERATION ON BINARY ASTEROID. M. Kanamaru¹ (E-mail: kanamaru@eps.s.u-tokyo.ac.jp), G. Tommei², T. Okada³, N. Sakatani³, Y. Shimaki³, S. Tanaka³, T. Ishizaki³, H. Senshu⁴, T. Arai⁵, T. Sekiguchi⁶, N. Hirata⁷, H. Demura⁷, ¹The University of Tokyo (Japan), ²The University of Pisa (Italy), ³ISAS/JAXA (Japan), ⁴Chiba Institute of Technology (Japan), ⁵Maebashi Institute of Technology (Japan), ⁶Hokkaido University of Education (Japan), ⁷The University of Aizu (Japan).

Introduction: A binary asteroid is a step in the evolutionary path of a rubble pile asteroid¹. The DART spacecraft successfully completed an impact experiment on Dimorphos, the satellite of a binary asteroid Didymos in September 2022. The Hera spacecraft will then arrive at the binary asteroid for proximity observation. A thermal infrared imager (TIRI) developed by ISAS/JAXA will be onboard on Hera. It will acquire the thermal properties of the binary asteroid and provide fundamental data for planetary defense.

Combined with the asteroid thermography, we also investigate the non-gravitational acceleration (NGA) on the binary asteroid, which has a great role in its long-term evolution. We aim to estimate and detect the NGAs on Didymos and Dimorphos: A change of the heliocentric orbit (Yarkovsky), a spin change of the primary (YORP), and a mutual orbit change of the secondary (binary YORP or BYORP).

We hereby report on the development of a thermophysical model to simulate the temperature distribution on the binary asteroid and estimate the NGAs on them.

Thermophysical Model (TPM): We have been developing a dynamical simulator for an asteroid, *Astroshaper.jl*^{*}. The simulation code was originally developed for predicting the YORP effect on asteroid Ryugu, the target asteroid of the Hayabusa2 spacecraft mission². We extended the functions for the thermophysical modeling to apply to a binary asteroid. It can calculate temperature distribution over primary and secondary asteroids considering some fundamental thermophysical processes: 3D shape models, 1-dimensional heat conduction in the depth direction, shadowing by the local horizon (self-shadowing), reabsorption of scattered light and thermal radiation by interfacing facets (self-heating), and eclipse by a pair of the asteroids (mutual-shadowing). The mutual heating effect that warms the facing hemispheres to each other and the thermal infrared beaming by surface roughness³ will be implemented in the future.

The orbital and rotational motion of Didymos and Dimorphos was input into the TPM code from the

SPICE kernels dataset[†] provided by the Hera mission. Thermal properties typical for an S-type asteroid are given such as thermal inertia $\Gamma = 403$ tiu. To eliminate the effect of the temperature distribution initially given (0K at all facets and all depth cells), TPM was performed for two months as a “warm-up” (from January 1st to March 1st, 2027, corresponding to ~627 rotations for Didymos and ~119 mutual orbit cycles for Dimorphos). We confirmed that the calculation sufficiently converged in terms of the balance between the energy input and output on the surface of each asteroid, where the energy conservation fraction⁴ $E_{\text{cons}} = E_{\text{out}}/E_{\text{in}}$ was greater than 0.98 at the final time step. For the later analysis, we used the simulated temperature data for 24 hours on March 1st, 2027.

Results: The upper panels of Figure 1 show the temperature maps of Didymos and Dimorphos at the epochs of the mutual events (eclipse and occultation). In the upper left panel, Dimorphos cast the shadow around (20°S, 90°W) of Didymos at 5:37 a.m. After 5.96 hours later or half of the orbital period of Dimorphos, one can observe Dimorphos hiding in the shadow of Didymos (upper left panel). The lower panel shows the temperature variation at the points indicated by the blue circle on the upper maps. Rapid temperature drops due to eclipse can be observed.

Non-Gravitational Acceleration. Using the above temperature distribution, we also calculated the thermal recoil force on each facet of the shape model and integrated it over the surface to obtain non-gravitational force and torque on the binary asteroid. By averaging over several rotations, the torque components for rotational acceleration were estimated as $\bar{\tau}_1 = 0.19 \text{ N}\cdot\text{m}$ for Didymos and $\bar{\tau}_2 = -1.1 \times 10^{-4} \text{ N}\cdot\text{m}$ for Dimorphos. It suggests that the rotation of Didymos is accelerating at the so-called YORP time scale of 4.1×10^6 years, that is, a time to double the rotation speed. On the other hand, the negative acceleration of Dimorphos decelerates its rotation at a

^{*}Asteroid dynamical simulator, *Astroshaper.jl*. (<https://github.com/MasanoriKanamaru/Astroshaper.jl>)

[†] SPICE kernel dataset for Hera mission (https://repos.cosmos.esa.int/socci/projects/SPICE_KERNELS/repos/hera/). The following pre-arrival shape models were used for our TPM:

- g_50677mm_rad_obj_dida_0000n00000_v001.obj
- g_06650mm_rad_obj_didb_0000n00000_v001.obj

for Didymos and Dimorphos, respectively.

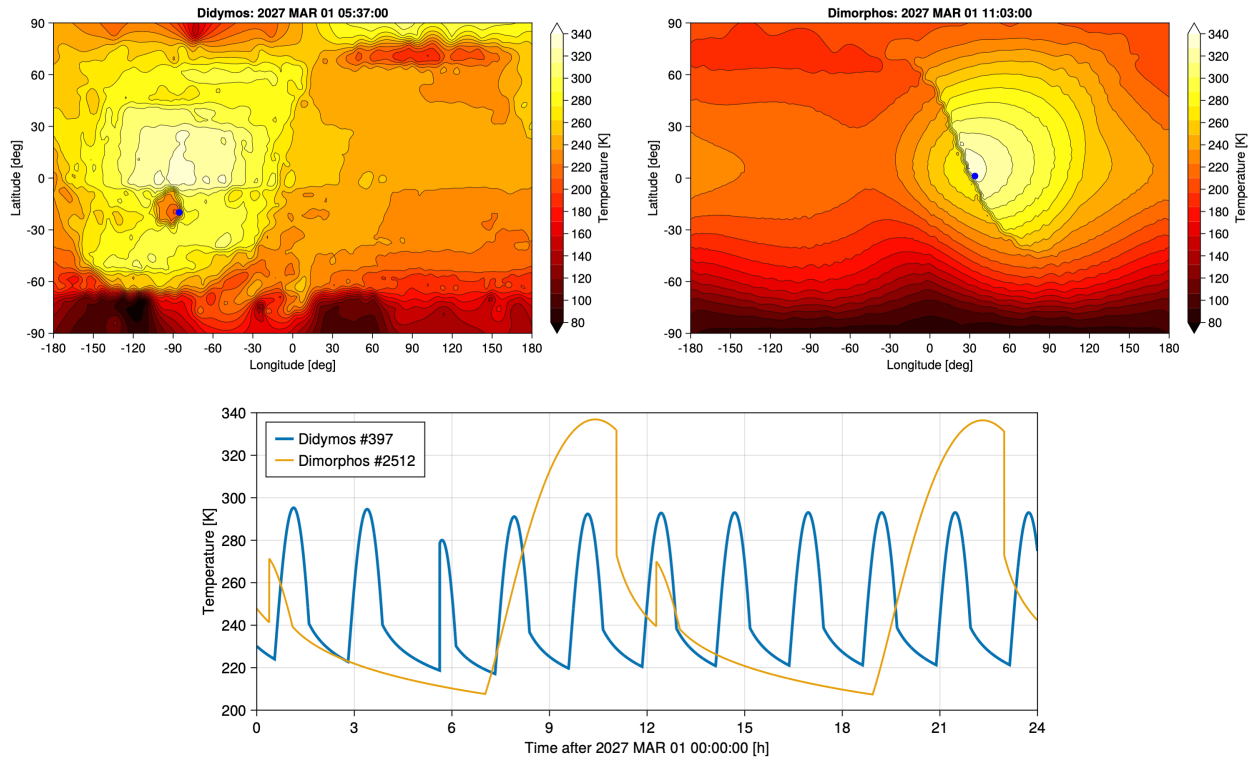


Figure 1. (Upper) The temperature maps of Didymos and Dimorphos on March 1st, 2027. The map is for the different time when an eclipse occurs at each body. (Lower) Temperature changes at the points indicated by blue circles in the maps.

time scale of 8.6×10^4 year reducing the rotation speed by half.

Discussion: Generally, the resolution of a pre-arrival shape model is not sufficient for YORP prediction that is sensitive to small-scale topography⁵. For a more precise prediction for Didymos and Dimorphos, we need to wait for Hera's rendezvous. The pre-arrival shape model of Dimorphos used in this study is an ellipsoid based on ground-based observation. The symmetrical shape should cancel out the torque, but the asymmetry of the temperature distribution results in the non-zero torque. Cooling due to the eclipse of Dimorphos is likely the cause of the negative acceleration. The drastic change in temperature may have the effects of expanding the mutual orbit of the binary asteroid and shortening its dynamical lifetime.

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